5/11-90
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N91-14211

ONE-DIMENSIONAL CLOUD FLUID MODEL FOR PROPAGATING STAR FORMATION

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I. INTRODUCTION

The aim of this project was to study the propagation of star formation (SF) with a self- consistent deterministic model for the interstellar gas. The questions explored are: (1) Under what conditions does star formation propagate in this model?, and (2) What are the mechanisms of the propagation? In our study, we have used the deterministic Oort-type cloud fluid model of Scalo and Struck-Marcell (1984, also see the review of Struck-Marcell, Scalo and Appleton 1987). This cloud fluid approach includes simple models for the effects of cloud collisional coalescence or disruption, collisional energy dissipation, and cloud disruption and acceleration as the result of young star winds, HII regions and supernovae. An extensive one-zone parameter study is presented in Struck-Marcell and Scalo (1987).

II. RESULTS

To answer the questions above we carried out one-dimensional calculations for an annulus within a galactic disk, like the so-called solar neighborhood of the galactic chemical evolution. In the calculations the left-hand boundary is set equal to the right hand boundary. The calculation is obviously idealized, however, it is computationally convenient to study the first order effects of propagating star formation. The annulus was treated as if it were at rest, i.e., in the local rotating frame. This assumption may remove some interesting effects of a supersonic gas flow, but was necessary to maintain a numerical stability in the annulus.

A. When Does SFR Propagate?

Two initial perturbation types were studied: pure density or pure SFR perturbations in the 10 zones at the center of a 100 zone grid. (Note: in these calculations SFR is measured by the relative rate of cloud break-up due to star-formation activity as parametrized by Scalo and Struck-Marcell.) The initial density perturbation was an over-density of three times the equilibrium density. With low values of the time delay parameter (defined as the ratio of the mean cloud lifetime to the mean cloud collision time), the cloud fluid behaved much as one would expect. SFR propagated out with the shock wave or acoustical waves that formed from the initial perturbation. Starbursts did occur in the zones of the initial perturbation. The pressure from these bursts reinforces the outward propagating SFR wave while depleting the gas. With a small time delay, the SFR indicator is linearly dependent on the density in regions away from the initial density perturbation. With larger values of the time delay parameter the effective critical density for bursts is lowered, so that the initial conditions are nearly in the burst regime. As a result of feedback from bursts the SFR profile is no longer linearly dependent on the density profile in perturbed regions. In the small time delay case, the density amplitude is damped out with time. However, in the long time delay model, the bursting reinforces the outward propagating shock waves. The shock waves amplify the density perturbation, pushing these zones further into the bursting regime. The most intense star formation occurs in the shock regions, which are defined by abrupt velocity changes. This supports the idea that star formation propagates through pressure disturbances, in this Oort-type model.

If the disturbance consists of SFR enhancement in pressure equilibrium, will the SFR still propagate? In this case, the SFR perturbation is created by increasing the mean cloud mass, at a constant mass density. Two different strength SFR perturbations were used: one of moderate strength in which the cloud mass was increased by a factor of 1.26, and a relatively strong one with a cloud mass increase of 2.0. The weaker perturbation, with an initial SFR increase of 2.52, did not propagate. The second perturbation, with an SFR enhancement of 16.0, did propagate, but not as efficiently as a

density perturbation. The stronger SFR perturbation sets up shock waves and it is these shock waves that propagate the star formation.

To summarize, pressure waves, reinvigorated by bursts of SF seem to be the chief propagation mechanism in this cloud fluid model. Density enhancements play an important role, but a global density wave is not required to trigger propagating SFR.

B. SFR Interference

When two adjacent density perturbations are set-up some distance apart, the waves they generate initally propagate outward just like the waves from a single perturbation, until the waves encounter one another. Then the two opposing wave fronts cause a large density increase in the zones between them. These zones are pushed into the burst regime, setting up a new source for star formation. The SFR in the zones of interference becomes oscillatory, in the same manner as if we had placed an initial perturbation in these zones.

C. Random Noise

Our study of the effects of random noise consisted of using an initial density perturbation amplitude, as above, plus a random background noise of maximum amplitude 0.1. As expected, the random noise has a strong effect on the local SFR within the annulus if the density is initially near threshold. In zones that are near the burst regime, positive amplitude noise is able to induce bursting, and negative amplitude noise can effectively prevent bursting. Zones with densities that are far from the bursting regime are not strongly affected, and the SFR in these zones responds with a linear dependence density noise. While these results are not surprising, they are important to keep in mind in comparing simulations to galaxies with SFR 'noise' of indeterminate amplitude. It also raises the possibility that noise modulation of a hydrodynamical wave, could significantly complicate the observational recognition of that wave.

Skillman (1986) and Kennicutt (1989 and references therein) have recently presented observational evidence that the star-forming regions in disks are near the critical density for gravitational instability according to Toomre's Q parameter, and that SF falls off rapidly outside of such regions. These results and our simulation results suggest the possibilility that the "normal" mode of SF in disks is a random burst mode, involving essentially the same physical processes as in density wave induced SF and nuclear starbursts.

III. CONCLUSIONS

We can summarize the results on the one-dimensional propagation of SF in the Oort cloud fluid model as follows. 1) SF is propagated by means of hydrodynamic waves, which can be generated by external forces or by the pressure generated by local bursts. SF is not effectively propagated via diffusion or variation in cloud interaction rates without corresponding density and velocity changes. 2) The propagation and long-range effects of SF depend on how close the gas density is to the critical threshold value, i.e. on the "susceptibility" of the medium.

This work supported in part by NASA grant NAGW 1009.

Kennicutt, R. C., Jr., preprint "The Star Formation Law in Galactic Disks" (1989).

Scalo, J. M. and Struck-Marcell, C., Astrophys. J., 276, 60 (1984).

Skillman, E., in "Star Formation in Galaxies Proceedings" ed. C. J. Lonsdale (Washington: NASA) (1986).

Struck-Marcell, C. and Scalo, J.M., Astrophys. J. Suppl. 64, 39 (1987).

Struck-Marcell, C., Scalo, J. M., and Appleton, P. N., in "Star Formation in Galaxies Proceedings" ed. C.J. Lonsdale (Washington: NASA) (1986).

Titus, T. N., M.S. Thesis, Iowa State Univ. (1988).